

Io Plume Observations from Galileo and HST

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Summary

Observations by the Galileo Solid State Imaging (SSI) experiment [1] and by the Hubble Space Telescope (HST) have both yielded surprises with respect to airborne volcanic plumes on Io. As of late 1996 SSI has detected far fewer bright visible plumes than were seen by Voyager in 1979. Although the SSI data return is strongly limited by tape and downlink resources, we are now confident that the general paucity of bright plumes is real. There are many high-temperature hot spots on Io during late 1996 [2, 3], so the general level of volcanic activity remains high. Johnson et al. [4] proposed the existence of "stealth" plumes on Io, high-entropy eruptions of gas with few entrained particulates, transparent at visible wavelengths. A July, 1996 observation by HST shows that Pele had a plume ~400 km high that could be detected at 255 nm but not at 340 or 410 nm, consistent with an SO₂ gas absorption or the presence of very fine particles. Furthermore, a Galileo E4 image acquired in December, 1996 at 153° phase angle shows the top of Pele's plume, indicating a height of 460 ± 20 km. Pele's plume was 300 km high during Voyager 1, so this is the largest plume yet detected on Io. We now confirm that the Pele plume is often and perhaps continuously active, and may be a near-stealth plume.

Voyager Observations and Galileo Expectations

The 2 Voyager flybys in 1979 revealed 9 plumes that are large (> 50 km) and bright (visible at uv to blue wavelengths in low-phase images exposed for imaging of surface features) [5]. The plume of Pele was the faintest, and was seen only during Voyager 1. All of these plumes could be seen in Voyager images with resolutions from 10-30 km/pixel. Voyager plumes (except Pele) were relatively brightest in the uv bandpass (~340 nm), but also easily seen in the violet bandpass (~413 nm). The plumes are best seen at high phase angles, as they are more forward-scattering than the surface. Voyager acquired more than 100 full-disk images at better than 30 km/pixel during each flyby, but many of these are highly redundant. One or more plumes are detectable in more than 50% of the Voyager full-disk images, either at the bright limb, near or beyond the terminator, or in stereo views. SSI's shortest bandpass is violet (~414 nm, comparable to

the violet bandpass of Voyager), and the camera has improved geometric and radiometric characteristics. Galileo's tour provides multiple opportunities to image Io at 10-30 km/pixel during every orbit, and often at higher phase angles than the Voyager approach images. Although SSI can acquire and return far fewer images per orbit than did Voyager, they are less redundant and the improved sensitivity of SSI aids the detection of plumes (especially during eclipse). We expected to see plumes in at least half of the SSI images of Io.

SSI Observations of Plumes.

SSI observations and plume detections are tabulated in [1]. From G1 images we determined that there are no visible plumes at Loki, and discovered new plumes at Ra Patera (~75 km high) and a small plume (~50 km high) south of the Voyager-era plume Volund. A G1 image with Pele at the bright limb revealed no evidence for a plume except for a 1-DN enhancement in the green-filter image, which cannot be considered a believable detection by itself. The G1 eclipse image and G2 images marginally detect a new small plume (< 50 km high) at Culann Patera. Orbit G2 included a sequence of 31 highly-compressed violet-filter images designed to acquire a global inventory of large (> 50-75 km) bright plumes, but only Prometheus was clearly seen. In fact, Prometheus can be detected in 8 of these frames, so the high compression ratio was not eliminating detectability of large, bright plumes. The G2 sequence and a C3 image show that Ra's plume was no longer visible. An E4 image available 1/9/97 revealed a new plume at ~ 103° W, 20° N at least 30 km high (depending on its actual location), which corresponds to the location of a hot spot discovered by NIMS [3]. This same E4 image (violet filter, 153° phase angle) reveals a large, faint plume that is probably the top of Pele, indicating a height for Pele of 460 km. There are no signs of the Voyager-era plumes Loki-west, Loki-east, Masubi, Volund, Amirani, Maui, or Marduk, in spite of observations that should have revealed these plumes if similar in size and brightness to the Voyager-era plumes. Hence the late 1996 inventory of large (> 50 km), bright plumes on Io consists of Prometheus, Ra (G1 only), and perhaps two other plumes (Table 1.)

PLUMES ON IO: McEwen et al.

Table 1. Plumes on Io, late 1996

Plume	Position	Height	When Seen
Pele	256 W, 18 S	460 km	7/96, 12/96
Prometheus	152 W, 2 S	75 km	9/96, 11/96
Ra	325 W, 8 S	75 km	6/96
near Volund	173 W, 18 N	>30 km	6/96
Culann	160 W, 19 S	< 50 km	6/96, 9/96
new plume	103 W, 20 N	>30 km	12/96

Detection of the Pele Plume by HST

There was a probable HST detection of Pele against black sky in July of 1995, at 255 nm. On July 24, 1996, one month after the first Galileo remote-sensing observations of Io, HST imaged the Pele plume against Jupiter's disk in the ultraviolet: the first unambiguous detection of the Pele plume since 1979. Io was imaged in transit across Jupiter's disk in the F255W filter with the WFPC2 camera, with a spatial resolution of about 140 km/pixel. Two images with exposures of 600 and 500 seconds were followed by a third 500-second F255W image 1.25 hours later. The F255W filter has a wavelength range from about 237 to 281 nm, shortward of Io's SO₂ absorption cutoff at 310 nm, so Io is very dark in this filter and appears in silhouette against Jupiter in the transit images. A dark patch is apparent extending from Io's limb in the first two images (Figure 1), and is also present but less apparent in the third image. The location and shape of the dark patch is consistent with the position of the Pele volcano, whose vent was 5° and 7° from the limb in the first two images, and 18° from the limb in the third image (accounting for the reduced plume size). The high signal-to-noise ratio of the images, the presence of the darkening on multiple frames, and its coincidence with the shape and location of Pele, make the plume detection convincing. We estimate the plume height to be about 400 km, with a mean optical depth of about 0.13.

Non-detection of Pele at longer wavelengths

The 255 nm HST images were immediately followed by images at 340 and 410 nm, which did not show the plume. We estimate a plume optical depth of less than 0.04 at 410 nm, so the 255:410 nm optical depth ratio is > 3.2. The much greater optical depth in the uv suggests that particles larger than the wavelength of the light do not contribute significantly to the plume opacity. Rayleigh scattering would give an 255:410 nm optical depth ratio of 6.7, consistent with the observations. The plume opacity may be dominated by Rayleigh-like scattering by submicron particles, perhaps similar to the < 0.01 micron radius

particles inferred in the outer part of the Loki plume in Voyager 1 images [6]. Rayleigh scattering by gas with reasonable column densities cannot provide sufficient opacity [6]. Alternatively, it is possible that SO₂ gas could be optically thick in the F255W filter due to molecular absorption [7], and that the observed plume opacity may thus be due entirely to gas absorption. In this latter case, the Pele plume observed by HST would be an example of a "stealth" plume [4].

Comparison with Galileo observations

Galileo observed intense thermal emission from the Pele vent in June and September 1996, consistent with temperatures exceeding 800 K [2, 3], but did not detect the Pele plume in its images, taken at 410 nm and longer wavelengths. The Galileo non-detections could be due to the strong wavelength dependence of the plume opacity that was seen by HST, which only detected the plume at 255 nm, but could also be a result of temporal variations in plume activity or visibility, as seen by Voyager at Pele. Pele was also not detected in the SSI eclipse image [2], predicted to be a method for detection of stealth plumes [4]. SSI finally imaged Pele in E4, as described above, at a high phase angle (153°) consistent with the presence of fine dust particles.

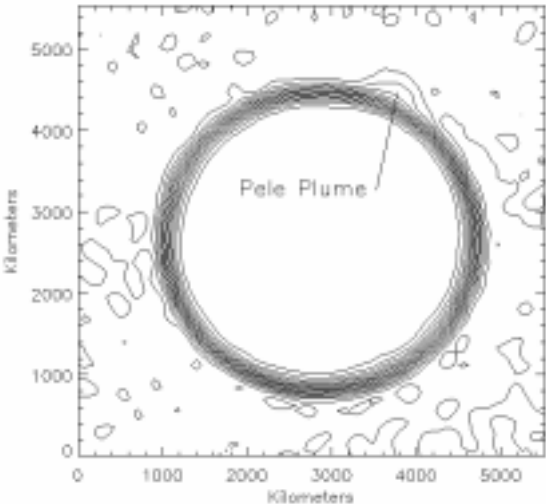


Figure 1. Contour version of an ultraviolet (237-281 nm) HST image of Io transiting Jupiter, showing the Pele plume off Io's limb. Note that Pele and Io's disk are darker than Jupiter, which fills the frame. This map derived from an average of the first two frames of the observing sequence.

References: [1] McEwen, A., et al., this volume. [2] Belton, M.J.S., et al. (1996) Science 274, 377. [3] Lopes, R., et al., this volume. [4] Johnson, T.V., et al. (1995) GRL 22, 3293. [5] Strom, R.G., et al. (1981), JGR 86, 8593. [6] Collins, S.A., (1981) JGR 86, 8621. [7] Sartoretto, P., et al. (1996) Icarus 122, 273.